

square foot, and the wind velocity can reach 270 meters per second, or 600 miles per hour. Whatever may be thought as to the actual development of such velocities and forces in this tornado, it is evident that sufficient power has been revealed to account fully for all the mechanical forces that were observed and considered by engineers. Mr. Julius Baier thought that something like 100 pounds per square foot had been expended in the destructive effects, but it is evident that much greater forces were really available near the center of the tube. At some distance from the center, in the tubes  $\sigma_3=375$  meters to  $\sigma_4=240$  meters, the pressures were apparently from 175 to 450 pounds per square foot. The subordinate minor whirls, or small vortices caused by the wind twining around obstacles, builds up the so-called frictional coefficient. In the free air the value of  $k$  is apparently a negligible quantity, and large values of  $k$  are confined to a thin surface layer.

TABLE 51.—Approximate pressure in pounds per square foot exerted by the wind in the St. Louis tornado.

$$\Delta B = 0.001742 \frac{B}{T^2}.$$

Tubes.	(1)	(2)	(3)	(4)	(5)	(6)	(7)
$q$	15.10	24.25	38.94	62.60	100.91	168.75	270.06
$B$	0.737	0.727	0.717	0.707	0.697	0.689	0.677
$T$	294.	294.	294.	294.	294.	294.	294.
$\Delta B$ (mm.)	9.96	25.31	64.42	164.16	420.33	1091.5	2925.6
$\Delta B$ (pounds per square foot)	27.66	70.37	178.96	456.03	1167.7	3032.1	8127.2

1 mm. mercury = 2.778 pounds per square foot.

must take on an additional velocity as soon as the cold layer is placed upon it. Now, in the St. Louis tornado a cold mass of air was carried forward over the warm mass of stagnant air that had been lying over the city for several days, and in a few hours the temperatures fell about  $18^\circ \text{F.} = 10^\circ \text{C.}$ , the tornado occurring at the vertical junction of two masses of air at different temperatures, as in Table 30. It seems probable that the warm air instead of mixing vertically with the cold sheet, slid out horizontally in all directions, that is radially from the point of greatest temperature contrast, like the spokes of a wheel held horizontally above the head. If the velocities  $u, v, w$  in Tables 38, 39, and 40 are examined at the higher sections  $az = 180^\circ$  or  $az = 170^\circ$ , it is seen that in this vortex the radial velocity above survives. Hence, we infer that the cause of this tornado was the horizontal flow of the warm air away from a center under the cold overflowing sheet, and that this radial action, whose purpose is to counteract the pressure change brought by the overflowing cold sheet, then propagated itself vertically downward in a dumb-bell-shaped vortex till it was cut off by the rough surface of the country and city at a section corresponding to an inflow of  $i = 30^\circ$ , as found in the observations. This example of the effects of horizontal convection suggests the forces which are operating in the atmosphere during the mixture of warm or cold currents. Similar reasoning assigns the same cause for the generation of hurricanes, which are deep tornadoes of the dumb-bell shape (see fig. 8). The same action can be traced to about half the area of large ocean cyclones, but the inner rings show that the horizontal convection is due in part to the sheets of cold and warm air standing vertically, while in the land cyclone the

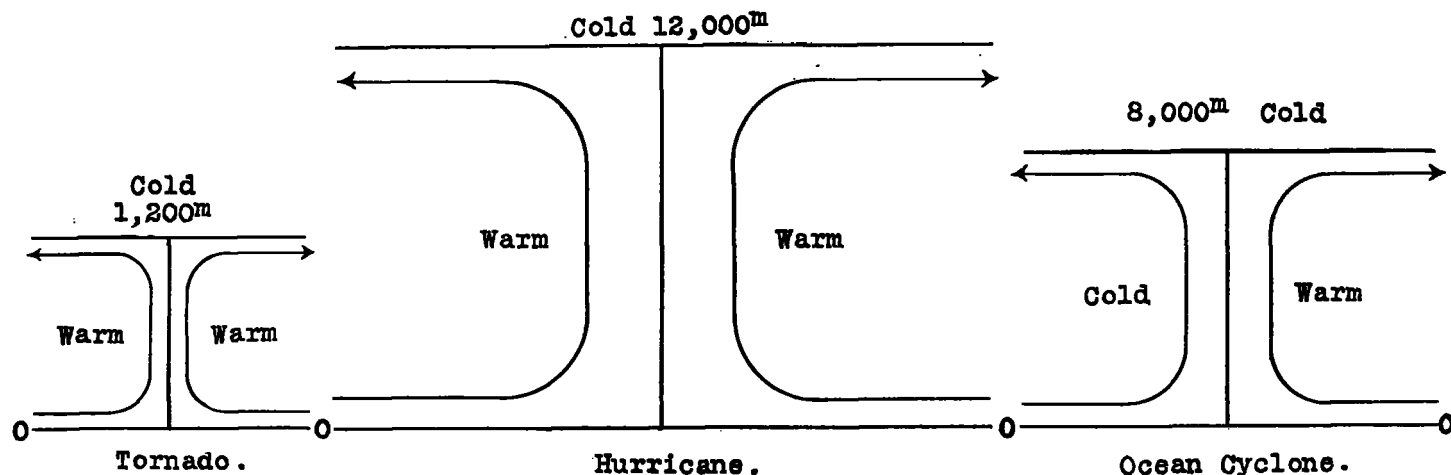


FIG. 8.—Diagram of the cold and warm masses of air in the tornado, hurricane, and ocean cyclone.

#### THE CAUSE OF THE FORMATION OF THE ST. LOUIS TORNADO.

In the last section of the first paper of this series on vortex motions it was shown that when two masses of air of different temperatures overlay one another, as a cold layer over a warm layer, there is a discontinuity in the pressure, caused by the different densities. But since in the air these discontinuities in the pressure can not persist under the forces of gravity, there is an immediate setting up of certain currents of motion which tend to destroy these pressure discontinuities and to restore a simple pressure gradient, such as is consistent with the prevailing temperatures. These temperatures and velocities are connected by the formula,

$$T_1(v_1^2 - v_0^2) = T_2(v_2^2 - v_0^2)$$

in which  $T_1$  and  $v_1$  are the temperature and average velocity, respectively, of the warm layer and  $T_2$  and  $v_2$  are the temperature and velocity of the cold layer and  $v_0$  is the average velocity of the layer before disturbance.

Since the temperature of the cold layer,  $T_2$ , is connected with the motion of the warm layer, it follows that the warm layer

vertical position of the plane separating the warm air from the cold air prevails and gives very impure vortices, tho their general typical features still survive.

The hurricane will be illustrated by the De Witte typhoon of August 1-3, 1901.

#### A TWO YEARS' STUDY OF SPRING FROSTS AT WILLIAMSTOWN, MASS.

By Prof. WILLIS I. MILHAN, Ph. D. Dated Williamstown, Mass., August 11, 1908.

##### INTRODUCTION.

Spring frosts have been quite extensively studied, chiefly on account of the damage caused by them which has excited popular interest in their prediction and in methods of protection against them. Among the more recent articles by those connected with the U. S. Weather Bureau may be mentioned:

Cline, I. M., "Irregularities in Frost and Temperature in Neighboring Localities." Third Convention of Weather Bureau Officials, Proceedings. Washington, D. C., 1904, p. 250.

Garriott, E. B., "Notes on Frost." Farmers Bulletin, No. 104.

Hammon, W. H., "Frost." W. B., No. 186.

McAdie, Alexander G., "Frost Fighting." W. B., No. 187.

It would be entirely impracticable here to attempt to mention all the literature on the subject. Abstracts of the original articles and references to them can, however, be found in the third volume of the *Fortschritte der Physik* for each year. They are given under the headings "Lufttemperatur," "Vorausbestimmung des Wetters," "Wetterschäden und Versuche zu ihrer Verhütung," and it would be necessary to cover about thirty years in order to be sure of finding all the articles of value.

The transition from the frosts of late winter or early spring to those of the late spring is unusually very well marked in Williamstown. It occurs normally a little after the middle of April. The wind will hold from the west or northwest for

vention are here omitted, the various investigations of frost can be grouped into three classes:

1. The prediction of the probable minimum temperature from observations of weather conditions made during the previous afternoon. For a long time the idea prevailed that by following a simple formula the probable minimum temperature could be computed from the maximum and the dew-point, or the reading of the wet-bulb thermometer, of the afternoon before. This method has been tested, not alone for the cool days when a frost might be expected, but for all the days of the various months and at many stations and for a long time. The general conclusion has always been that the uncertainty is too great to make the method of any value in forecasting.

2. The variation in the severity of the frost at different

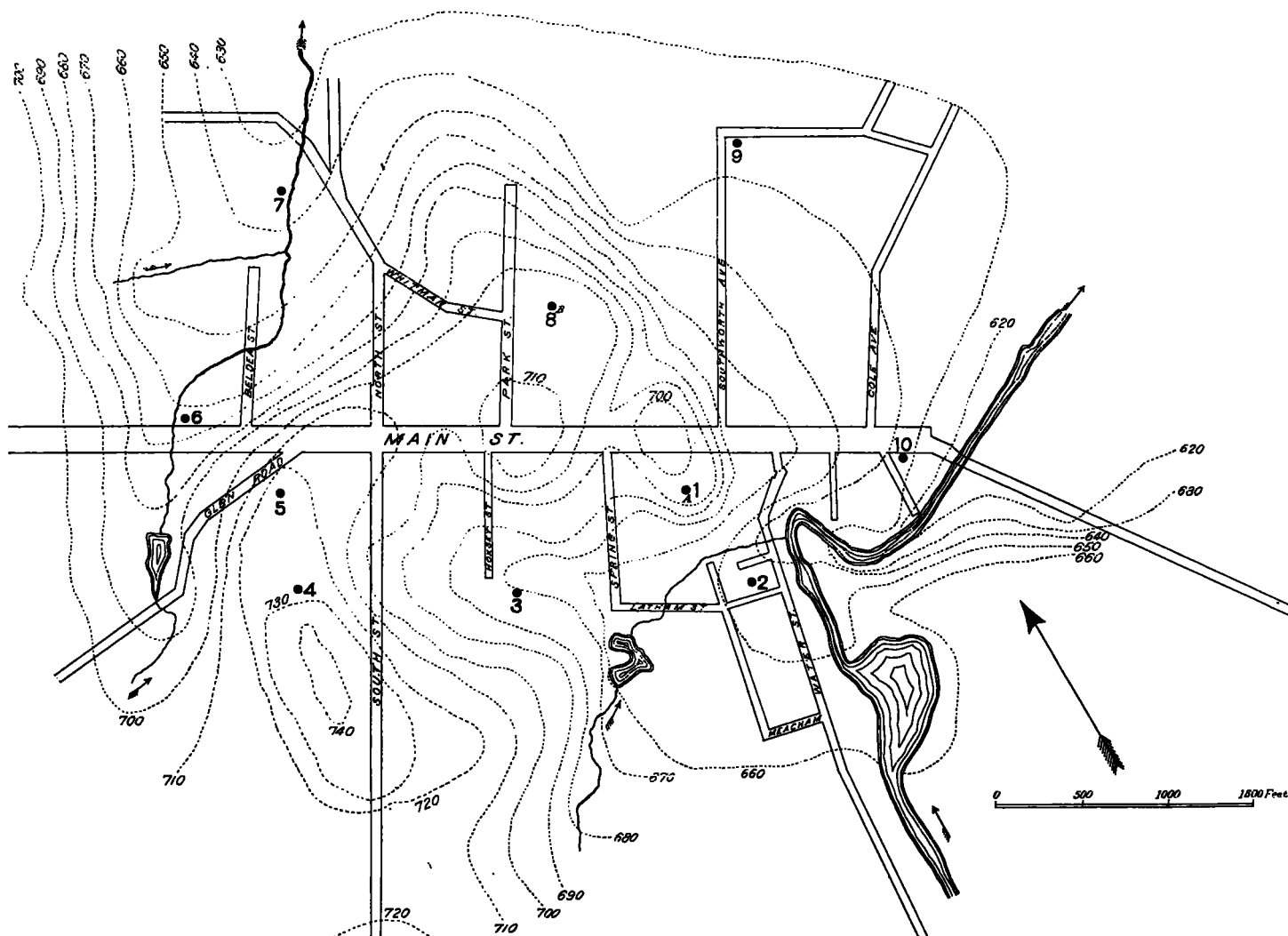


FIG. 1.—Contour map of Williamstown, Mass.

several days, accompanied very often by snow flurries, and the ground freezes solid at night. This marks the end of the winter régime and is the last unusually cold period. The wind then goes to the east or southeast, copious rain falls, the temperature rises markedly, vegetation makes rapid progress, and the air contains much more moisture. Those frosts which occur after this are of an entirely different nature and may be termed the spring frosts. These are the ones which do the damage to the growing vegetation.

#### THE LINES OF INVESTIGATION.

If the consideration of the practical methods of frost pre-

places within a small area. Several times it has been observed that even within a small area the frost would be much more severe at one place than another, and the valleys and places of small elevation are usually found to be the coldest.

3. Variation in the severity of the frost with varying distance above the ground. The statement is sometimes made that the variation of temperature with distance above the ground is so marked in the lower 2 or 3 feet that the lower branches of shrubs may be frozen while the top escapes.

It is the purpose of this article to study, critically, the spring frosts at Williamstown during 1907 and 1908, in order

to come to as definite and exact conclusions along these three lines as can be formed.

A complete description of the village, together with an accurate topographic map<sup>1</sup>, may be found in the MONTHLY WEATHER REVIEW for July, 1905, vol. XXXIII, p. 306. The three stations mentioned later in this article are practically identical with the stations numbered 1, 8, and 7 on the map, fig. 1. The village of Williamstown is particularly suited for this investigation because this limited area has been carefully investigated<sup>2</sup> for two years for variations in temperature over it under different conditions.

#### THE THERMOMETERS AND THEIR EXPOSURES.

Williams College is a cooperative station of the U. S. Weather Bureau and the shelter which contains the psychrometer and the registering thermometers, all of the regular Weather Bureau form, is located on the north side of the astronomical observatory, which is unheated. The shelter (*A* in fig. 1) is a sufficient distance from the building to allow proper ventilation and is located over sod. The instruments are 5½ feet above the ground. For the investigation of the frosts one station (1 in fig. 1) was chosen in the open about 15 feet northwest of the thermometer shelter. One reason for choosing such a location for one station was to be able to connect the series of readings with the indications of the thermometers in the shelter. Another station (7 in fig. 1) was located at the bottom of the valley, 66 feet lower than the first station, about 3,000 feet distant from, and almost due north of the shelter. The reason for choosing this location was the fact that in the investigation on variation of temperature<sup>3</sup> this station had always shown itself to be by far the coldest part of the village. A third station (8 in fig. 1), chosen largely as a check, was located about half-way between stations 1 and 7, and very nearly in a line with them. Its elevation is 3 feet greater than that of station 1 near the shelter *A*. Stations 8 and 7 were over sod, but some grading had been done at 1 so that there the grass was short and the ground partly bare. In the investigations of variation in temperature over a limited area, station 7 was always the coldest, while stations 1 and 8 were among the three warmest.

At each station was placed a frame for holding the thermometers. The thermometers used were self-registering minimum thermometers of the regular Weather Bureau type and two were placed at each station. They were mounted on unpainted pine boards about 18 inches long by 7 inches wide and exposed entirely in the open without a shelter of any kind. One was placed 5½ feet above the ground and the other one-half foot above the ground. This brought the lower thermometer just above the grass. The thermometers were identical and certainly accurate, but as a final precaution they were tested both before and after this investigation.

#### THE PREDICTION OF THE MINIMUM TEMPERATURE FROM THE PRECEDING MAXIMUM.

The data from which the conclusions in this connection are drawn are given in Table 1. The first column contains the date which is always that of the day on which the maximum in question occurred. The minimum, of course, occurred on the morning of the following date. The second column contains the maximum temperature, and this always occurred between 2:30 and 4 p. m. The third, fourth, fifth, and sixth columns give the wind and sky observations at the time of the maximum. The four things given in order are wind velocity in miles per hour, wind direction, the proportion of the sky, in tenths, covered by clouds, the kind of clouds. In connection with the cloudiness 0 would indicate a cloudless

sky and 10 would indicate a sky totally covered. The next two columns give the dew-point at the time of the maximum and at 8 p. m., respectively. The next column contains the following minimum temperature, and after this comes the wind and appearance of the sky at the time of the minimum. The temperatures in Table 1 were all taken from thermometers inside the shelter, and the dew-points were computed from a psychrometer also located inside the thermometer shelter. This table contains the observations on all those cool nights between the last of April, 1907, and the first of June, 1908, when frost seemed possible. It contains observations for all nights when the minimum temperature went to 40° or below, and for a few when it did not fall quite to 40°.

TABLE 1.—Maximum and minimum temperatures on certain dates during the springs of 1907 and 1908 at Williamstown, Mass.

Date.	Afternoon.						Following morning.					
	Maximum.	Wind.		Clouds.		Dew-point.	Minimum.	Wind.		Clouds.		
		Vel.	Dir.	Amt.	Kind.			Vel.	Dir.	Amt.	Kind.	
1907.	°F.	mi. p. h.				°	°	°F.	mi. p. h.			
Apr. 27....	60	1	e.	0	.....	38	32	32	1	e.	0	
May 1....	51	4	nw.	10	Cu.	37	34	33*	4	e.	9	Cu.
May 4....	50	7	s.	10	N.	.....	30	.....	2	nw.	2	Cu.
May 5....	54	2	sw.	0	.....	29	34	38†	.....	.....	.....	
May 11....	46	8	nw.	7	Cu.	.....	29	27	2	nw.	0	†
May 12....	54	4	nw.	0	.....	26	32	42‡	0	.....	0	
May 20....	53	10	nw.	4	Cu.	31	28	37	4	nw.	3	Cu.
May 21....	53	10	nw.	2	Cu.	31	30	39	4	nw.	5	Cu.
May 22....	55	2	nw.	6	Cu.	33	38	.....	2	nw.	8	Cu.
May 23....	60	2	nw.	7	Cu.	42	37	.....	2	nw.	1	Cu.
May 24....	64	2	nw.	0	.....	36	33	.....	1	nw.	0	
May 28....	50	15	nw.	9	Cu.	33	27	37	6	nw.	0	
1908.												
Apr. 29....	58	3	sw.	5	Cu.	43	43	40	1	nw.	10	S.‡
May 1....	46	8	nw.	10	S.-cu.	30	33	39	1	nw.	5	Cu.
May 2....	56	2	s.	9	Cu.	44	44	35	20	w.	10	N.‡
May 3....	49	12	nw.	9	Cu.	41	37	35	1	nw.	0	
May 4....	57	7	nw.	3	Cu.	37	40	32	1	nw.	0	
May 5....	60	2	nw.	0	.....	39	41	46	1	nw.	0	
May 9....	51	6	nw.	10	N.	.....	37	39	8	nw.	9	Cu.
May 10....	51	6	nw.	9	Cu.	35	37	42	3	nw.	0	
May 14....	64	5	e.	10	N.	.....	47	40	4	e.	9	Cl.-Cu.

\* Minimum at 3:30 a. m. † Minimum at 12:30 a. m.; rained later. ‡ Snow flurries during p. m. § Minimum at 12:10 a. m. ¶ Night cloudless. ¶ Snow during night.

When this investigation was begun the author held the preconceived idea that even if the minimum temperature could not be computed with certainty from the preceding maximum, yet the characteristics of those cool spring nights when a frost seemed probable would be so nearly the same that here such a computation would be a possibility. It would seem that if the dew-point were not past, the drop in temperature ought to be very nearly a constant on different nights. And if the dew-point were past it would seem that there would be a certain fractional lessening of the further amount of drop on account of the latent heat given out by the condensation of moisture. The drop in temperature from the maximum to the following minimum could thus be expressed by a formula such as:

$$\text{Drop} = t_m - t_d + A\{B - (t_m - t_d)\}$$

where  $t_m$  = maximum,  $t_d$  = dew-point,  $A$  and  $B$  are constants. This would of course hold only for those cases where  $t_m - t_d$  is less than  $B$ . For all other cases the formula would be simply

$$\text{Drop} = B.$$

The constants  $A$  and  $B$  could be determined from a series of observations since the drop,  $t_m$  and  $t_d$  are quantities which can be observed.

As soon as observations began to be made it was seen at once that the dew-points were extremely low and that the minimum temperatures in most cases were above the dew-points, or at most only a few degrees below. That means that on these cool days when a frost seems probable, the air is so dry that the dew-point plays practically no part in determining the minimum temperature, since there seems to be

<sup>1</sup> The map is reprinted here for the convenience of the reader.

<sup>2</sup> See the Monthly Weather Review for July, 1905, XXXIII, p. 305, and for August, 1906, XXXIV, p. 370.

<sup>3</sup> See Monthly Weather Review, loc. cit.

no retardation of cooling due to the liberation of latent heat after the temperature has past the dew-point. It is thus to be expected that the drop in temperature would be a constant. Now, the average drop for 1907 and 1908, neglecting those nights when the minimum came before sunrise, is  $16.9^{\circ}$ , and the greatest and least values are  $31^{\circ}$  and  $7^{\circ}$ . It will be seen at once that the amount of the drop is very far from a constant. One is thus forced to the following conclusions:

1. The cool nights of spring, when a frost might be expected, are very dry and the dew-point lies so low that it plays practically no part in determining the minimum temperature.

2. The amount of the drop from the maximum to the following minimum is very far from a constant, even if the characteristics of these nights seem very nearly the same. In each case, in estimating the probable drop, one must take into account the probable amount of cloud, the probable wind velocity, the possibility of a change in wind direction, and possibly other things.

It was intended to extend this investigation over the past ten years, but as soon as the above conclusions became certain it seemed unnecessary to publish the observations for more than the two years. The previous records were, however, carefully gone over to be sure that 1907 and 1908 were not unique years and that they bore out the above conclusions. It should be mentioned in passing, that no lack of ventilation on the part of the psychrometer can account for the low dew-points. If the instrument had been poorly ventilated, the wet-bulb reading would have been too high and the computed dew-point would be too high rather than too low.

#### VARIATION IN TEMPERATURE DIFFERENCES OVER A LIMITED AREA.

The conclusions as to areal variations in the severity of the frosts are based upon the observations given in Table 2. The

TABLE 2.—Observations at 8 p. m., and the following minimum temperatures at three stations and two elevations in Williamstown, Mass.

Date.	Temperatures at 8 p. m.				Wind and clouds.				Minimum.			
	A	1	8	7	Velocity.	Dir.	Amt.	Kind.	A	1	8	7
	° F.	° F.	° F.	° F.	mi. p. h.				° F.	° F.	° F.	° F.
1907.												
April 27.....	51	50	48	42	1	e.			32	30	27	27
April 27.....	48	45	38				0		30	27	23	
May 1.....	46	43	40	35	1	nw.			33	29	28	25
May 1.....	42	36	30				0		28	25	21	
May 4.....	34	34	34	34	15	nw.			30			
May 4.....	34	34	34	34			8	Cu.				
May 5.....	45	48	40	37	0				38	36	32	31
May 5.....	42	37	34				10	Cl.	34	32	27	
May 11.....	37	37	37	37	6	nw.			27	25		18
May 11.....	37	37	37	37			6	Cu.	24			15
May 12.....	44	43	41	36	1	uw.			42	41	39	33
May 12.....	43	38	31				0		40	36	31	
May 20.....	45	44	42	42	7	nw.			37	35	34	34
May 20.....	48	40	40				4	Cu.	35	32	31	
May 21.....	42	42	40	42	5	nw.			39	38	36	36
May 21.....	42	38	39				1	Cu.	38	34	33	
May 22.....	49				2	nw.			38		31	
May 22.....							6	Cu.			28	
May 23.....	32				2	uw.			37			
May 23.....							6	Cu.				
May 24.....	53				2	nw.			33	31		25
May 24.....							0		30			20
May 28.....	44	43	42		12	nw.			37	36	34	31
May 28.....	42	42	40				0		36	32	31	
1908.												
April 29.....	50	49	47	40	2	w.			40	38	37	35
April 29.....	49	47	40				10	S.	38	36	34	
May 1.....	42	40	39	40	1	nw.			39	37	35	31
May 1.....	39	37	38				2	Cu.	36	32	28	
May 2.....	48				1	s.			35			
May 2.....							10	N.				
May 3.....	45	44	44		2	nw.			35	33	31	31
May 3.....	44	44					7	Cu.	33	30	27	
May 4.....	46	46	39		1	nw.			32	30	28	28
May 4.....	45	46	36				0		30	27	24	
May 5.....	51	50	48		1	nw.			46	45	43	40
May 5.....	49	45						haze.	44	39	35	
May 9.....	44	42	42	42	6	nw.			39	39	38	38
May 9.....	42	41	42				6	Cu.	39	37	38	
May 10.....	46	45	44	44	6	nw.			42	40	38	36
May 10.....	45	44	44				4	Cu.	40	36	34	
May 14.....	49	47	46	43	1	nw.			40	39	39	36
May 14.....	47	45	40				0		39	37	34	

<sup>a</sup> Observations of thermometer 5½ feet above ground. <sup>1</sup> Observations of thermometer ½ foot above ground.

first column contains the date of the observation. In this column *u* refers to the upper thermometer, placed 5½ feet above the sod, and *l* to the lower thermometer, placed ½ foot above the sod. The next four columns contain the temperatures at 8 p. m., in the shelter *A* and at stations 1, 8, and 7. Succeeding columns give the wind and sky at 8 p. m., while the last four columns contain the minimum temperatures recorded in the shelter *A* and at stations 1, 8, and 7.

The chief results of these observations are summarized in Table 3. This table contains the average and the largest differences between the shelter *A* and station 1, station 1 and station 8, and station 1 and station 7, for both the upper and lower thermometers at the hours recorded.

It will be noticed the indications of identical thermometers in the thermometer shelter and at station 1 in the open only 15 feet away, and at the same height above the ground, differ by  $1.2^{\circ}$  F. at 8 p. m., on the average, and by an average of  $1.6^{\circ}$  at the time of the minimum. This is but a confirmation of the well-known fact that a thermometer in the open radiates its heat to the sky, and therefore indicates a temperature below the real air temperature. It is probably, however, an approximation to the temperature which vegetation would have in the same location, as this also radiates its heat. This difference is worked out on the assumption that the shelter gives the real air temperature. On still clear nights, however, it is a question if a thermometer placed in a shelter without artificial ventilation, does not indicate temperatures slightly above the true temperature of the outside surrounding air.

TABLE 3.—Summary of differences in temperature.

Stations.	Height of thermometers.	At 8 p. m.		At time of minimum temperature.	
		Average.	Largest value.	Average.	Largest value.
	Feet.	°	°	°	°
Shelter A and 1.....	5.5	1.2	3	1.6	4
1 and 8.....	5.5 0.5	1.2 2.3	3 6	1.8 3.2	4 5
1 and 7.....	5.5 0.5	3.6 5.4	9 12	4.0 6.4	8 10

The average difference for both the upper and lower thermometers between station 1 and station 8, and station 1 and station 7, is greater at the time of the minimum than at 8 p. m. Columns 3 and 5 of Table 3 present these contrasting values. This is what would naturally be expected, for the wind velocity averages greater at 8 p. m. than at the time of the minimum, and the variation over a limited area depends to a marked extent on wind velocity. The average difference is also greater for the lower thermometers than for the upper. This is also to be expected as the air near the ground would be held quiet by friction and replaced much more slowly than at a small height above it. The magnitude of the difference, particularly in the case of the lower thermometer, and the contrast between station 1 and station 7 are worthy of note. The average difference amounted to as much as  $6.4^{\circ}$  F. and the largest value was  $10^{\circ}$  F.

#### VARIATION IN TEMPERATURE DIFFERENCES WITH DISTANCE ABOVE THE GROUND.

The chief results of the study of the variations in temperature differences with distance above the ground are summarized in Table 4. The average value and the largest value of the difference between the indications of the upper and lower thermometers, at 8 p. m. and at the time of the minimum, are here given for the three stations.

TABLE 4.—Summary of observations, showing temperature difference with height.

Stations .....	At 8 p. m.			At time of minimum temperature.		
	1	8	7	1	8	7
Upper-lower:	°	°	°	°	°	°
Average difference.....	0.5	1.5	2.1	0.5	2.0	2.9
Largest difference.....	2	4	5	2	4	5

Three things are to be noticed: the smallness of the difference; the fact that the difference is greater at the time of the minimum temperature; and the fact that it is greatest at the coldest station. The largest average difference is only 2.9° and the actually largest value is only 5°. The difference is ordinarily supposed to be much larger than this. It is to be expected that the difference would be greater at the time of the minimum for the wind velocity is less. It is not altogether apparent why it should be greatest at the coldest station unless, as a valley station, it is more sheltered and the wind velocity is thus less.

## OTHER RESULTS.

There are certain well-known and almost self-evident facts in connection with frosts, which need only be mentioned in passing. A still clear night is almost essential for a large drop in temperature and a consequent frost. Wind mixes the air and thus prevents the lower layer from cooling excessively, while a clear sky is essential for that free radiation from the ground which is one of the chief causes of the cooling. The wind was almost without exception northwest when a frost occurred; and frosts were found to occur on the first or second night following the passage of a "low," when the weather of the area studied was in transition to the control of an approaching area of high pressure.

It will be noticed that the dew-point at 8 p. m. was sometimes higher and sometimes lower than it was at the time of the maximum temperature in the afternoon. Either state of things can be readily explained. If there were no importation of drier air by the wind, the continual evaporation of water vapor from the ground and vegetation ought to add moisture to the air during the afternoon and thus raise the dew-point. The importation of drier air, however, is often sufficient to counteract the effects of this process and cause a drop in the dew-point.

Two processes operate to produce the cooling which may result in a frost. These are first, the importation of cooler air, and second, the radiation of heat from the ground and the cooling of the air next to it by conduction. It might seem that the cool nights during which frosts seem probable, could be divided into two groups depending upon whether the importation of cold air or radiation from the ground was playing the larger part in producing the cooling. This is, however, hardly practicable, because both processes are nearly always operative. On some occasions a strong northwest wind will import cool, dry air, thus holding down the maximum temperature during the day and causing a low dew-point. If the wind dies down during the night and the sky becomes clear, it takes but little radiation to cause a frost. On other occasions there seems to be but little importation of cool, dry air, the sky is very clear and there is almost no wind. Radiation is excessive and the resulting large drops in temperature may cause a frost. While both processes are usually active, it is generally easy to see which predominates.

## SUMMARY.

The chief results and generalizations brought out in this study are summarized below. Of course these apply to Williamstown only, but the conclusions would probably be very similar for the whole of New England, and a similar set of data can be worked out for any place.

The so-called spring frosts may be expected from the last of April until the first of June and occur on still, clear nights, with the wind almost invariably from the northwest. They are likely to come on the first or second night following the passage of a low and the transition of the weather control to an area of high pressure. This facilitates both the importation of colder air and radiation, the two processes which cause the low temperatures required. The air is so dry and the dew-point lies so low that it plays no part whatever in determining the amount of the drop from the maximum to the following minimum. The drop is, however, far from a constant, and must be estimated for each individual case, taking into account the probable characteristics of the afternoon and night.

If, after the probable minimum temperature in the thermometer shelter has been estimated, it is desired to determine what the probable temperature of low-growing vegetation in the coldest part of the limited area will be, three things must be taken into account. First, that plant temperatures go below the real air temperatures, because the plants are in the open without such a hindrance to radiation as is the shelter about a thermometer; second, that vegetation is located near the ground and not at the height of the instruments in the shelter; third, that the variation in temperature over a limited area may amount to several degrees. Were this computation carried out with the average values for Williamstown, about 2° would be allowed for exposure in the open, 3° for height, and 6° for variation between the shelter and the coldest part of the area. Thus the temperature of vegetation in the open, near the ground, in the coldest part of the village may be expected to average 11° lower than the estimated minimum in the shelter as it is now located.

## GOVERNMENT METEOROLOGICAL WORK IN BRAZIL.

By Prof. ROBERT DE C. WARD, Harvard University. Dated, Curitiba, State of Parana, Brazil, August 6, 1908.

The following notes were made during a trip to Brazil in July and August, 1908, the object of which was to gather information, at first-hand, covering the climate, products, and development of that country. They are to be continued in the MONTHLY WEATHER REVIEW for September, 1908, where will also appear a map showing the location of the stations.

## METEOROLOGY AT THE NATIONAL OBSERVATORY.

The National Astronomical Observatory at Rio de Janeiro, Brazil, is situated on the Morro do Castello, one of the hills overlooking the city, in a very densely populated section close to the harbor. The building was once part of an old Jesuit monastery, and is today extremely picturesque and interesting, with its *patio* filled with trees and shrubs; its rambling stone stair-cases and passage-ways; its quaint architecture, and the crowded population which surrounds it. The oldest church in Brazil, built in 1567, forms a part of the pile of buildings in which the observatory is now placed. Rumor says there are vast stores of hidden treasure in the hill, beneath the old monastery, and excavations have been made from time to time, in order to discover these riches, but so far without success.

The offices of the observatory are in the upper story of the building, and the instruments are placed at various points on the roof. The thermometers (wet and dry bulb) and thermographs are well exposed at the top of one of the principal towers. The shelter has a double roof, double louvered sides, and is large enough to walk about in.

In the main office, directly beneath this shelter, are placed the standard mercurial barometer (Fuess), and the self-recording instruments, which are of the usual Richard Frères patterns. There is also a new and quite inexpensive English self-recording anemometer, constructed on the pressure-tube plan. This instrument has not yet proved altogether satisfactory.